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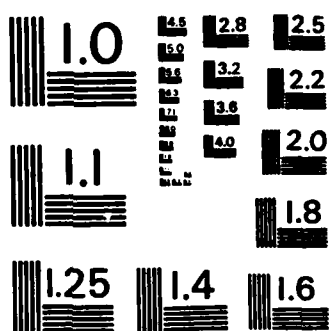
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**RESEARCH AND DEVELOPMENT NEEDS OF VERTICAL ATTITUDE
TAKEOFF AND LANDING (VATOL) AIRCRAFT**

by

Richard E. Kuhn

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AVIATION AND SURFACE EFFECTS DEPARTMENT

DTNSRDC/ASED-79/05

May 1979

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
ABSTRACT	1
ADMINISTRATIVE INFORMATION	1
INTRODUCTION	1
OPERATING CONCEPT	3
CONFIGURATIONAL CONSIDERATIONS	6
HIGH ANGLE OF ATTACK AND POST-STALL AERODYNAMICS LONGITUDINAL CHARACTERISTICS	7
LATERAL/DIRECTIONAL CHARACTERISTICS	14
CONTROL SYSTEM AND ENGINE MODIFICATIONS	20
CONTROL REQUIREMENTS	20
HOVER AND TRANSITION CONTROL CONCEPT	21
CONTROL IN OTHER MODES OF FLIGHT	23
RESEARCH AIRCRAFT	24
ALTERNATE ENGINE AND NOZZLE CONCEPT	25
CREW STATIONS	27
STO, TAXI, AND GROUND HANDLING GEAR	29
RESEARCH AND DEVELOPMENT NEEDS	29
PILOT TILTING	31
POST-STALL AERODYNAMICS	31
HANDLING QUALITIES	32
VECTERING NOZZLES AND ENGINE MODIFICATIONS	32
LANDING PLATFORMS	32
SPRAY SUPPRESSION	33
IFR (INSTRUMENT FLIGHT RULES) OPERATIONS	34

	Page
CONCLUSIONS	34
REFERENCES	35

LIST OF FIGURES

1 - VATOL Operating Concept	4
2 - Ryan X-13 VATOL in Hover	5
3 - VATOL Fighter	8
4 - VATOL Research Aircraft	10
5 - Estimated Longitudinal Aerodynamic Characteristics with Canard Undelected	13
6 - Thrust and Pitch Trim Required in Constant Altitude Transition	15
7 - Post-Stall, Lateral/Directional Characteristics of the X-13 Configuration	16
8 - Lateral/Directional Control in the Post-Stall Region	17
9 - Effect of Vertical Tail Configuration on Post-Stall, Lateral/Directional Characteristics	19
10 - Effective Radii of Gyration of Fighter Class Aircraft with Stores Off	22
11 - Alternate Nozzle and Engine Arrangement	26
12 - Articulating Crew Station	28
13 - VATOL Unique Research and Development Needs	30

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ABSTRACT

Previous studies have shown the vertical attitude takeoff and landing (VATOL) concept to have the least penalty for achieving vertical takeoff and landing capability. In this study, features are examined that should be included in a research aircraft to explore, develop, and demonstrate the full operational feasibility of the VATOL concept. Conceptual arrangements of two sizes of research aircraft designed around existing engines are presented, including the research and development needs.

ADMINISTRATIVE INFORMATION

This study was completed for the David Taylor Naval Ship Research and Development Center (DTNSRDC) under Navy Contract N00167-78-M2599 for the assessment of V/STOL technology. Mr. Kuhn was engaged in V/STOL aircraft research with the NASA Langley Research Center for many years. He now serves as a V/STOL consultant to both Industry and Government.

INTRODUCTION

The increasing size, cost, and vulnerability of military bases, both on land and on sea, have increased interest in vertical/short takeoff and landing (V/STOL) aircraft as a possible means of relieving these problems. Also, the requirements for combat maneuverability have resulted in modern fighter aircraft having thrust-to-weight ratios greater than one, appearing to make vertical takeoff and landing (VTOL) performance easy to achieve. There are, however, many compromises to make and losses to overcome in configuring fighter aircraft for VTOL capability. The number of the compromises, the size of the losses, and the resulting penalties in complexity and weight depend on the V/STOL concept. It is generally conceded that, purely from the airplane point of view, the vertical

attitude type airplane suffers the least penalty particularly with respect to weight increase.^{1,2*} All that is needed is a reaction control system, a device on the nose to engage the landing platform, and a means of tilting the pilot to maintain adequate visual cues. The problems typical of horizontal attitude types such as vectoring the thrust 90 deg, balancing the thrust above the center of gravity (c.g.), and the losses due to hot gas ingestion and aerodynamic suckdown are all avoided.

The vertical attitude type airplane, however, has a unique operational mode in that in transitioning to a landing, the airplane must be flown through the stall and the pilot's seat must tilt to allow adequate visual reference for the landing. Two aircraft, the Convair XFY-1 propeller driven tail sitter and the Ryan X-13 jet VATOL, have already demonstrated that this operation is not a serious problem. These aircraft have made numerous vertical takeoffs and landings and transitions to and from conventional flight, including a demonstration by the X-13 from the roadway in front of the Pentagon.

Although these flight programs were completed (over 20 years ago) without serious incident, they were not followed up because of the weight/performance penalties due to the then available technology. Modern engine, structures, and avionics technology has largely eliminated these penalties. There remains, however, concern about the operational feasibility of the concept in the hands of service pilots operating in field conditions in all kinds of weather.

*A complete listing of references is given on page 35.

A flight research program is needed to explore the operational problems, to develop and demonstrate solutions and operating techniques, and to determine the operational feasibility and limitations of the VATOL concept. Because the areas of concern relate only to the low-speed region of performance, it should not be necessary for the research aircraft to demonstrate the full supersonic fighter flight envelope. It should be possible to build such a research aircraft using available engines. This study presents a first cut at examining the feasibility of such a research aircraft, reviews a few of the unique configurational considerations, and outlines the key V/STOL related technology areas that must be covered in developing such a research aircraft.

OPERATING CONCEPT

The operating concept envisioned for shipboard service is shown in Figure 1. After a constant altitude transition from wing-born horizontal flight to jet-born vertical altitude, the aircraft would approach the landing platform which has been raised to the vertical position. A harpoon or hook on the lower forebody of the aircraft would engage a grid or wire on the landing platform to secure the aircraft. (The X-13 used a hook to engage a single wire, Figure 2.) Takeoff could be either a reverse of the landing sequence or, at higher gross weights, a short horizontal takeoff (using a ski jump on shipboard to reduce the deck length required³).

Although Figure 1 shows stern mounted platforms on a SWATH ship, there is nothing to restrict the concept to this position or ship type. Both stern and side mountings of the platforms on conventional monohulls

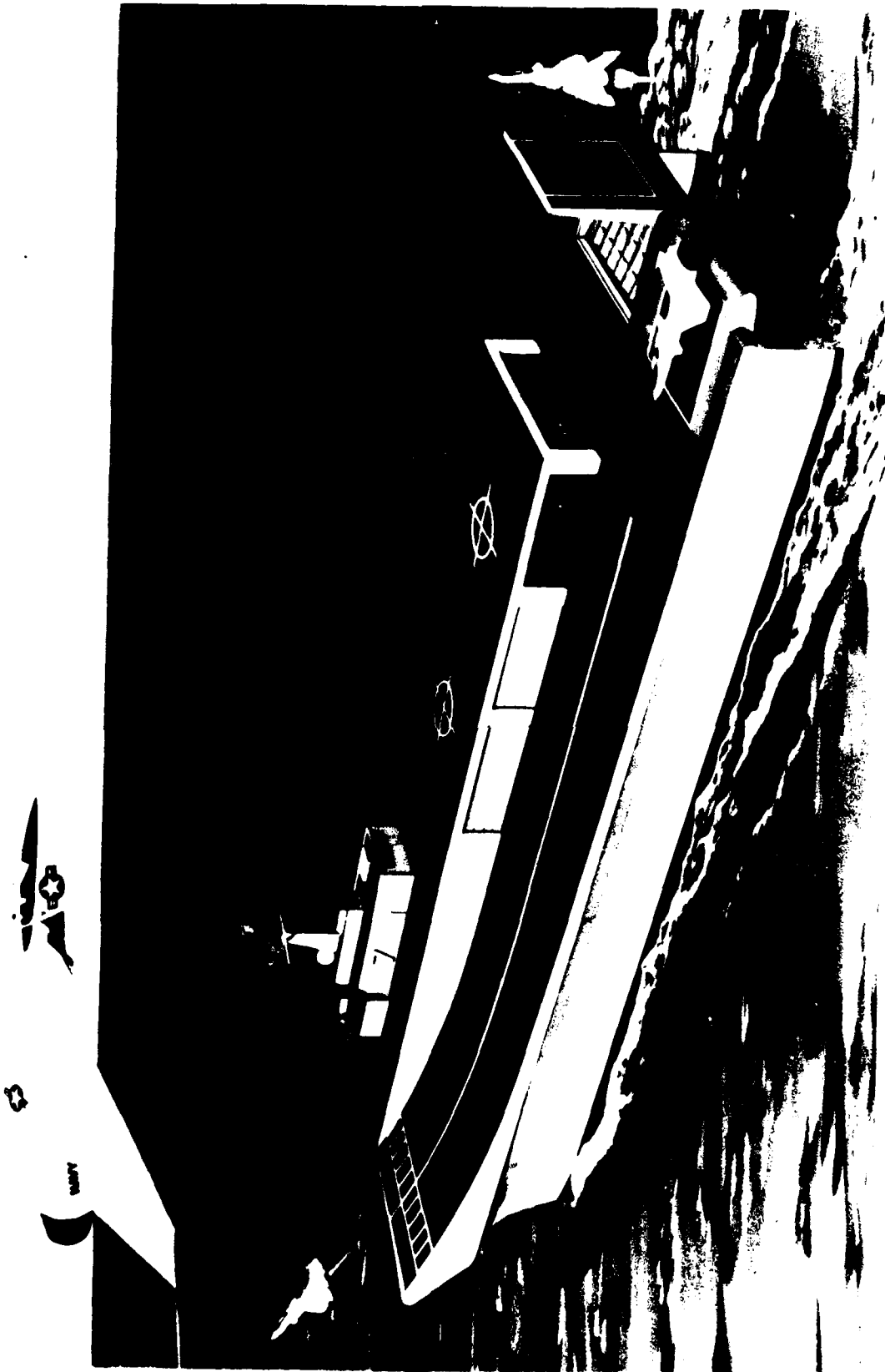


Figure 1 - VATOL Operating Concept

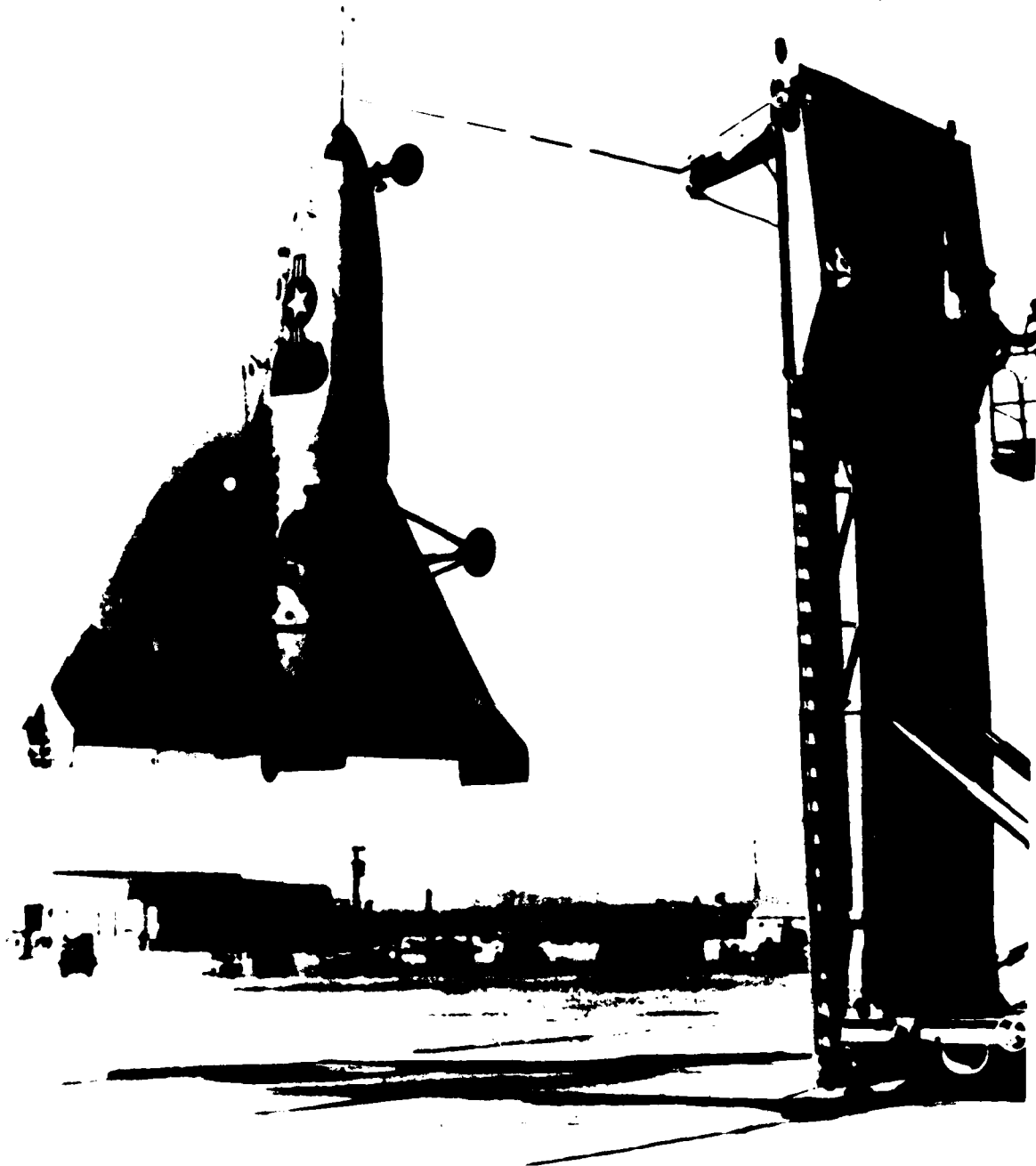


Figure 2 - Ryan X-13 VATOL in Hover

have been proposed. On land bases, the landing platforms would be mounted on a truck-trailer arrangement so that the platforms could be moved and dispersed.

CONFIGURATIONAL CONSIDERATIONS

The configuration of a VATOL research aircraft and the work to be done should be guided by the expected configuration and operations of an operational fighter and will be dictated primarily by the mission requirements. Special considerations for VTOL operation include:

1. Good post-stall aerodynamic characteristics. These characteristics are also desirable for good combat maneuverability and, therefore, will probably not significantly alter the configuration.
2. A reaction control system for hovering and transition control. Good control is also needed for high angle of attack maneuverability, and there is the possibility of developing one control system that would be satisfactory for all modes of flight.
3. Pilot tilting. The highly reclined seats of modern fighter aircraft would put the pilot in a head-down attitude in hovering. Some means of tilting the pilot and providing adequate inside and outside visibility throughout the transition is needed.
4. Landing gear. A conventional gear with high sink speed and large braking energy capability is not needed; however, some form of ground handling (perhaps with a capability to permit short takeoffs) is desirable.

Sketches of a hypothetical VATOL fighter using an advanced engine and of two possible research aircraft concepts designed around available engines are shown in Figures 3, 4a, and 4b. These aircraft have been sized

by standard methods^{4,5} to ensure that the performance, stability and control, and weights are reasonably realistic. The aircraft, however, have not been subjected to careful detailed design and are only conceptual arrangements intended to illustrate several of the unique features that should be considered in developing the VATOL concept. The following sections expand on these features.

HIGH ANGLE OF ATTACK AND POST-STALL AERODYNAMICS LONGITUDINAL CHARACTERISTICS

For both combat maneuverability and the transition from conventional flight to vertical attitude, it is desirable that the maximum lift coefficient and the angle of attack for stall be high and that the stall and post-stall regions be as free of abrupt changes in forces and moments as possible. The X-13 used a 60-deg delta wing to obtain a gentle, high angle-of-attack stall. More recently, work has been done by Headley,⁶ Lacey,⁷ and Gloss⁸ on vortex lift and the use of leading edge extensions and canards to delay and control the stall. As suggested by Lacey,⁷ a high mounted, close coupled canard with a 60-deg leading edge sweep has been incorporated in the configurations shown in Figures 3 and 4.

Experience with the X-13 by Girard^{9,10} and Girard and Everett¹¹ indicates that the buffet in the post-stall region was not a problem. Buffett was even a slight asset in that its changing character gave the pilot an additional indication of progress through transition.

The primary longitudinal problem encountered with the X-13 was that significant pitch trim was required during a constant altitude decelerating transition with the result that, according to Girard and Everett,¹¹

Figure 3 - VATOL Fighter

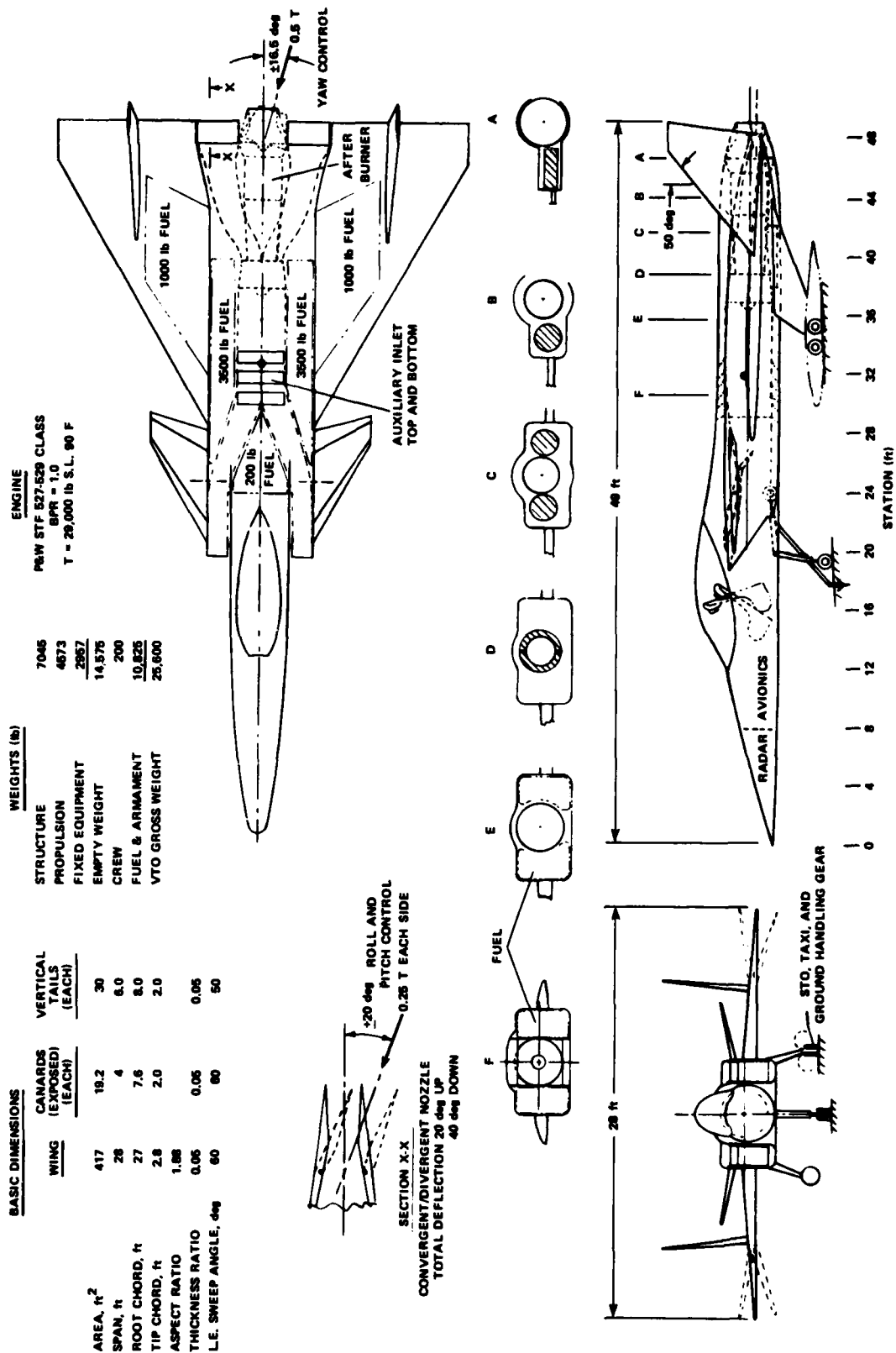


Figure 3a - Three-View

Figure 3 (Continued)

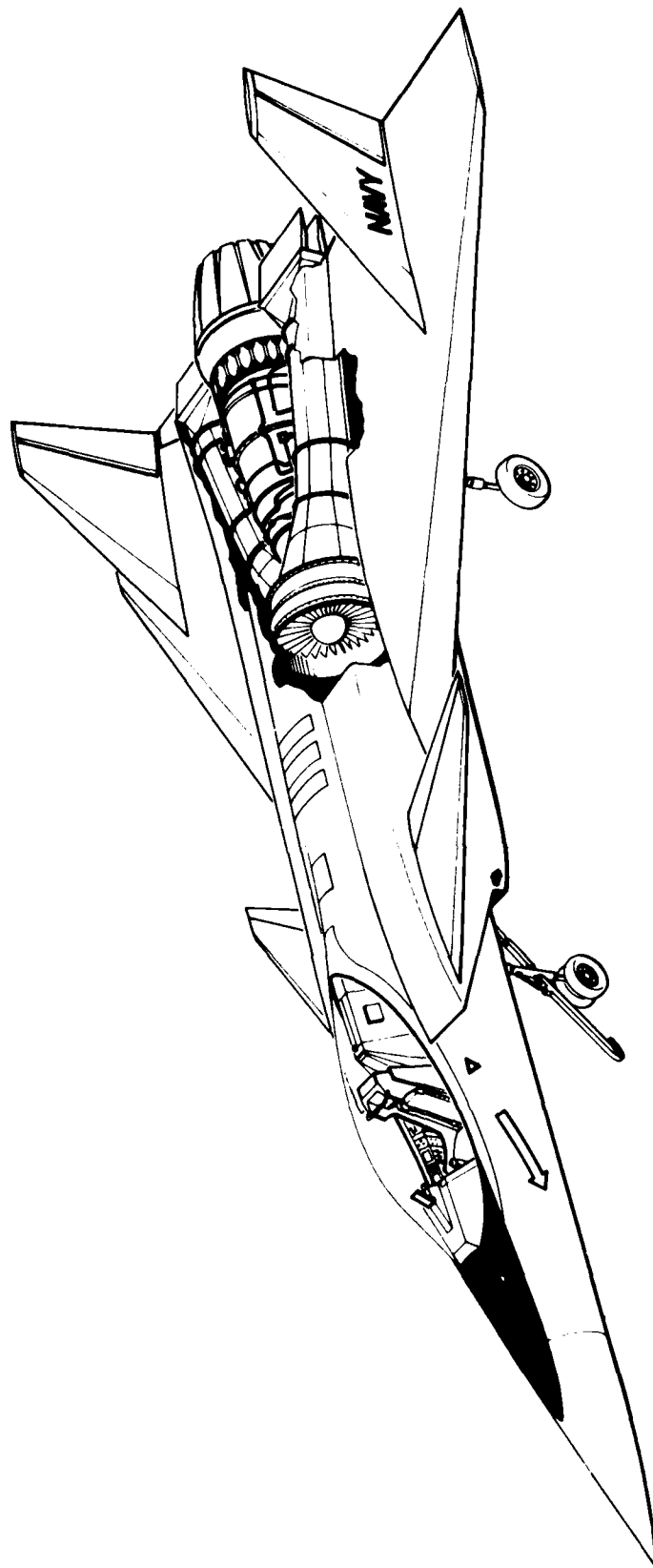


Figure 3b - Cutaway of Engine Installation

Figure 4 - VAtOL Research Aircraft

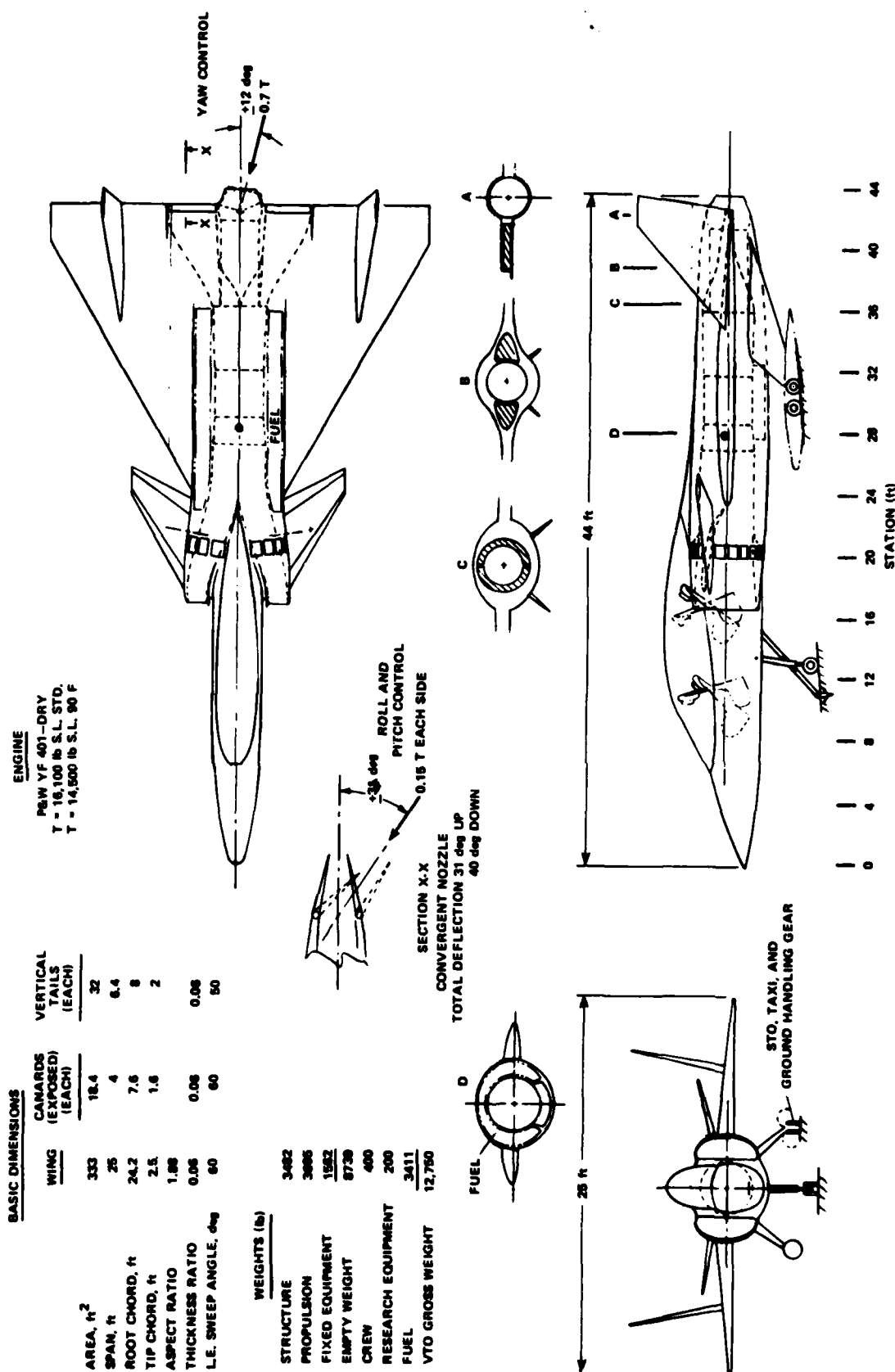


Figure 4 (Continued)

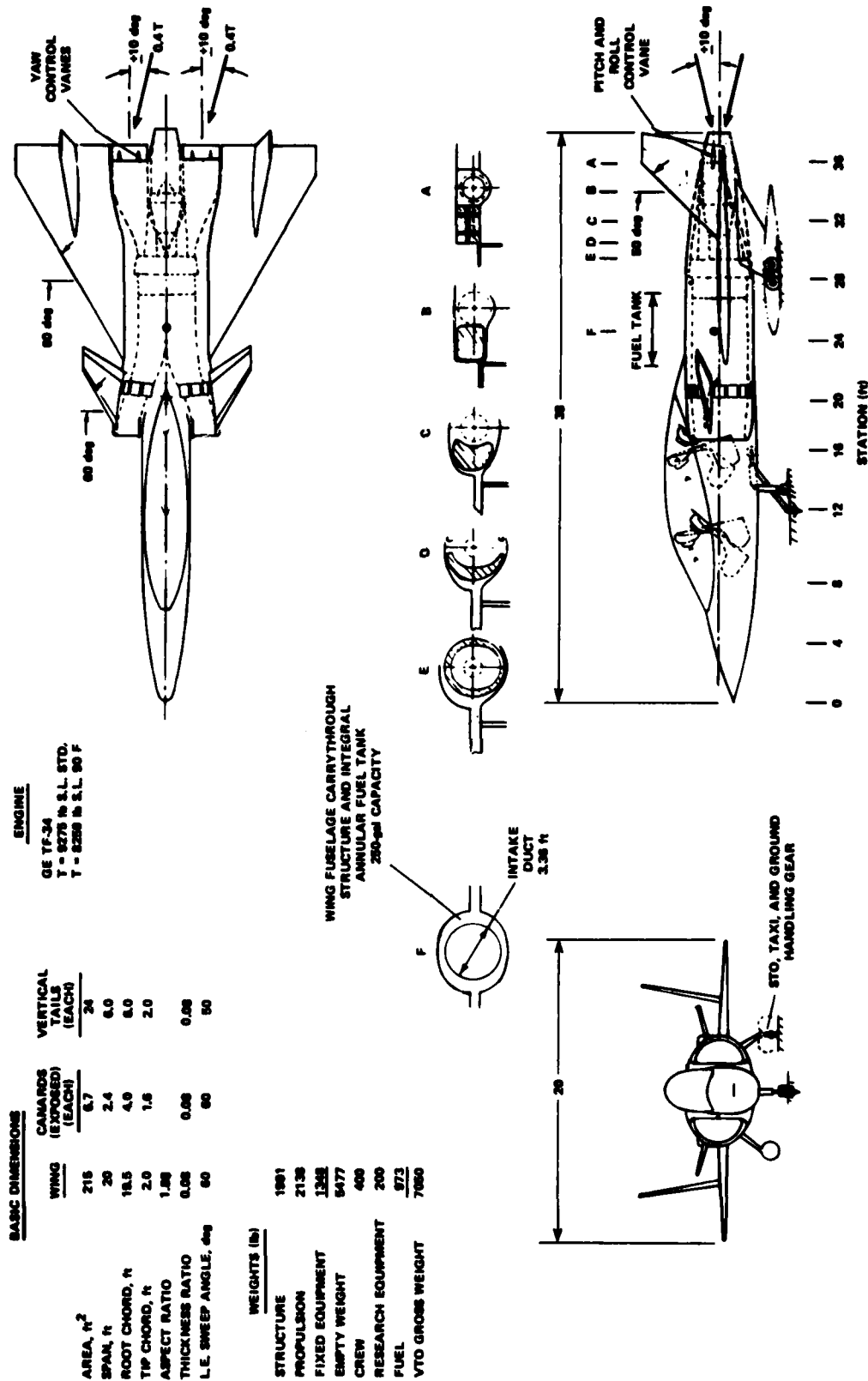


Figure 4b - General Electric TF-34 Engine

"the airplane could not be flown steady state at attitude angles between 32-deg and 70-deg due to an incompatibility between the thrust level required for constant altitude, and that required for longitudinal control, the latter requirement being the greater."

This incompatibility did not become a serious problem for the X-13 because the pilot soon developed a technique of pitching through this region at a relatively constant rate by "following a memorized schedule of engine rpm versus airplane attitude angle" (to avoid zooming). Nevertheless, this incompatibility is a condition to be avoided.

No design procedures or systematic data base are available to use in designing for optimum characteristics in the post-stall region; therefore, the desired characteristics will have to be developed in a wind-tunnel program. However, experience gained in the development programs of modern fighter aircraft has shown that the planform area and its distribution fore and aft of the c.g. are primary factors in determining the very high angle-of-attack characteristics. A canard configuration should be a help in minimizing the fore and aft imbalance of the configuration, particularly if the c.g. position is chosen for neutral or slightly negative stability in the conventional flight range.

The estimated longitudinal aerodynamic characteristics of the configuration are presented in Figure 5. The coefficients in the lower angle of attack range (conventional flight) were estimated by adjusting the data for the 60-deg canard configuration⁸ for the effects of aspect ratio and c.g. position. The top end of the angle of attack range was estimated using the data for the delta wing configuration¹² adjusted for the flap plate area and its distribution. The thrust and control

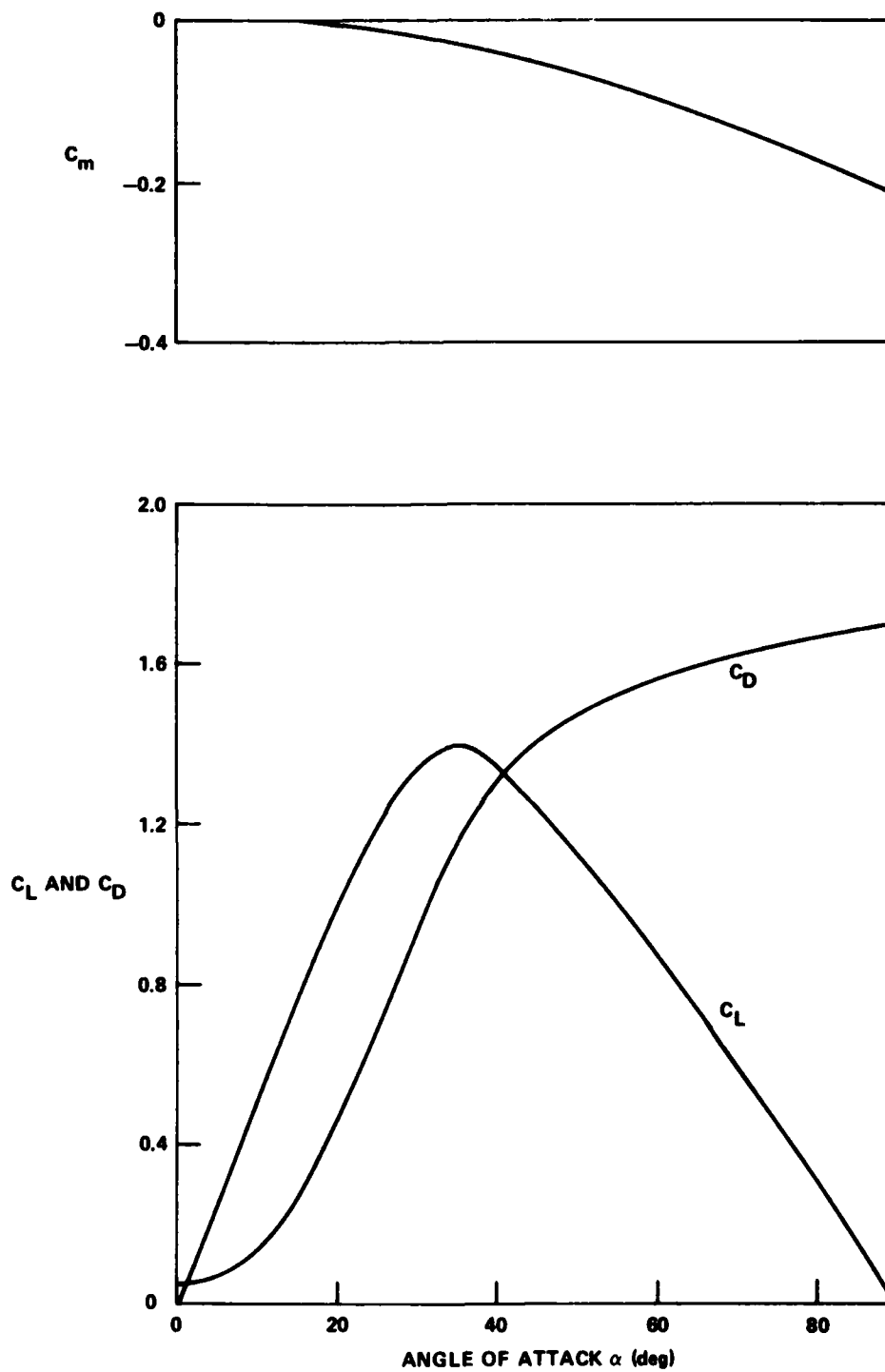


Figure 5 - Estimated Longitudinal Aerodynamic Characteristics with Canard Undelected

deflection required in constant altitude transition is shown in Figure 6 and indicates that it should be possible to keep the nozzle deflection required for trim well within the deflection range that can be easily provided. The thrust required is in good agreement with that required by the X-13 (which had very nearly the same aspect ratio wing).

LATERAL/DIRECTIONAL CHARACTERISTICS

Apparently, the lateral/directional characteristics of the X-13 gave the pilot of the X-13 the most trouble in the transition. Because of its small size and close coupled configuration, the X-13 had very low directional stability in conventional flight. At and beyond the stall, the airplane was directionally unstable. Even more serious was the abrupt reversal of dihedral effect at the stall. These characteristics are illustrated in Figure 7 (from Reference 13).

The data from the X-13 have been applied to the configuration of Figure 4b (approximately the same size and weight as the X-13) to illustrate the significance relative to the control levels usual for a VTOL aircraft, Figure 8. Note that the roll control required to handle extreme sideslip angles exceeds the control available in level flight by a considerable margin at and just beyond the stall. (The X-13 flying was limited to very small sideslip angles.) Also, adequate control is available at full power; but then the airplane would begin to climb.

These data are for a configuration with a central vertical tail and without the effects of the canard surfaces. Figure 9 from

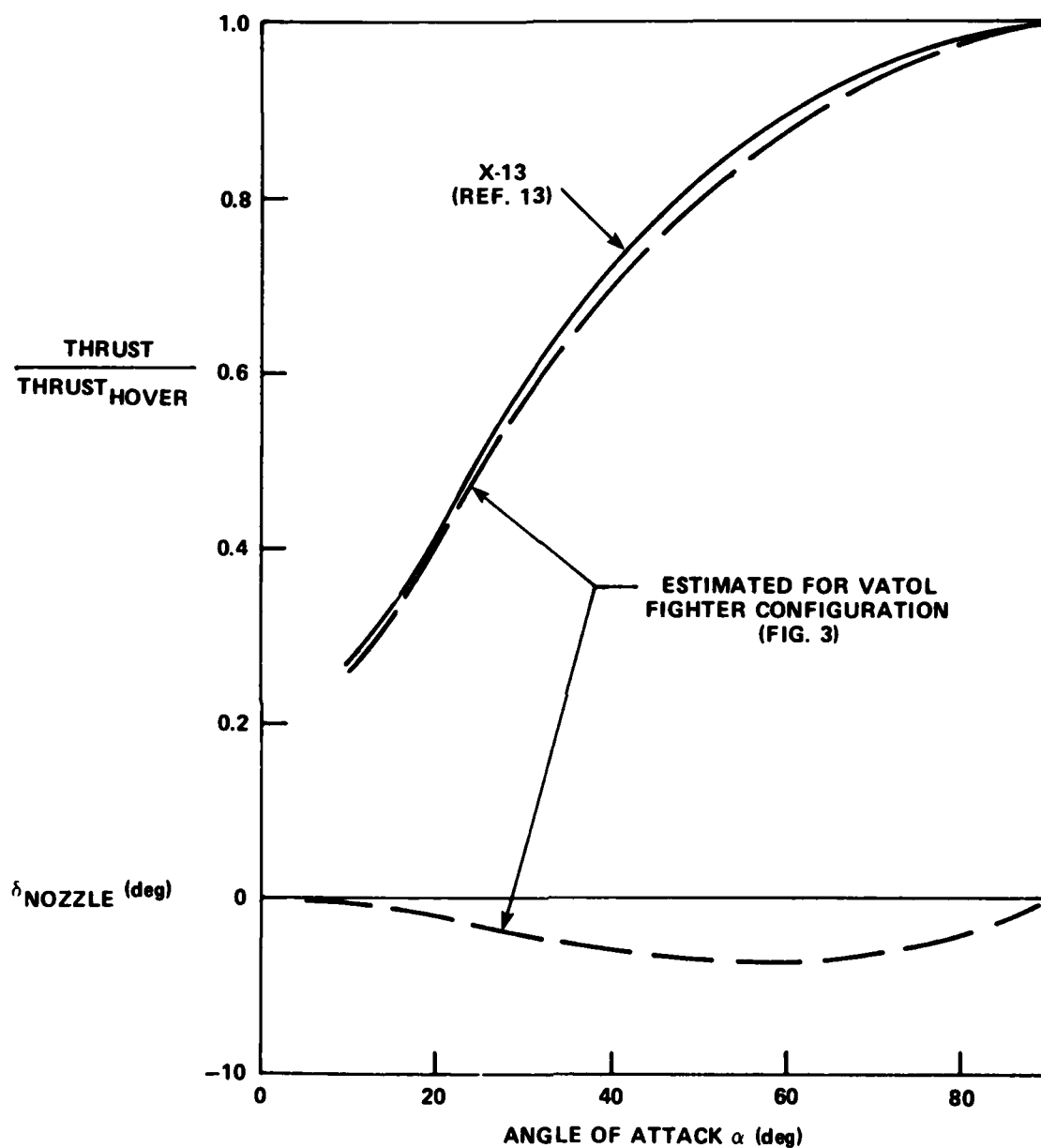


Figure 6 - Thrust and Pitch Trim Required in Constant Altitude Transition

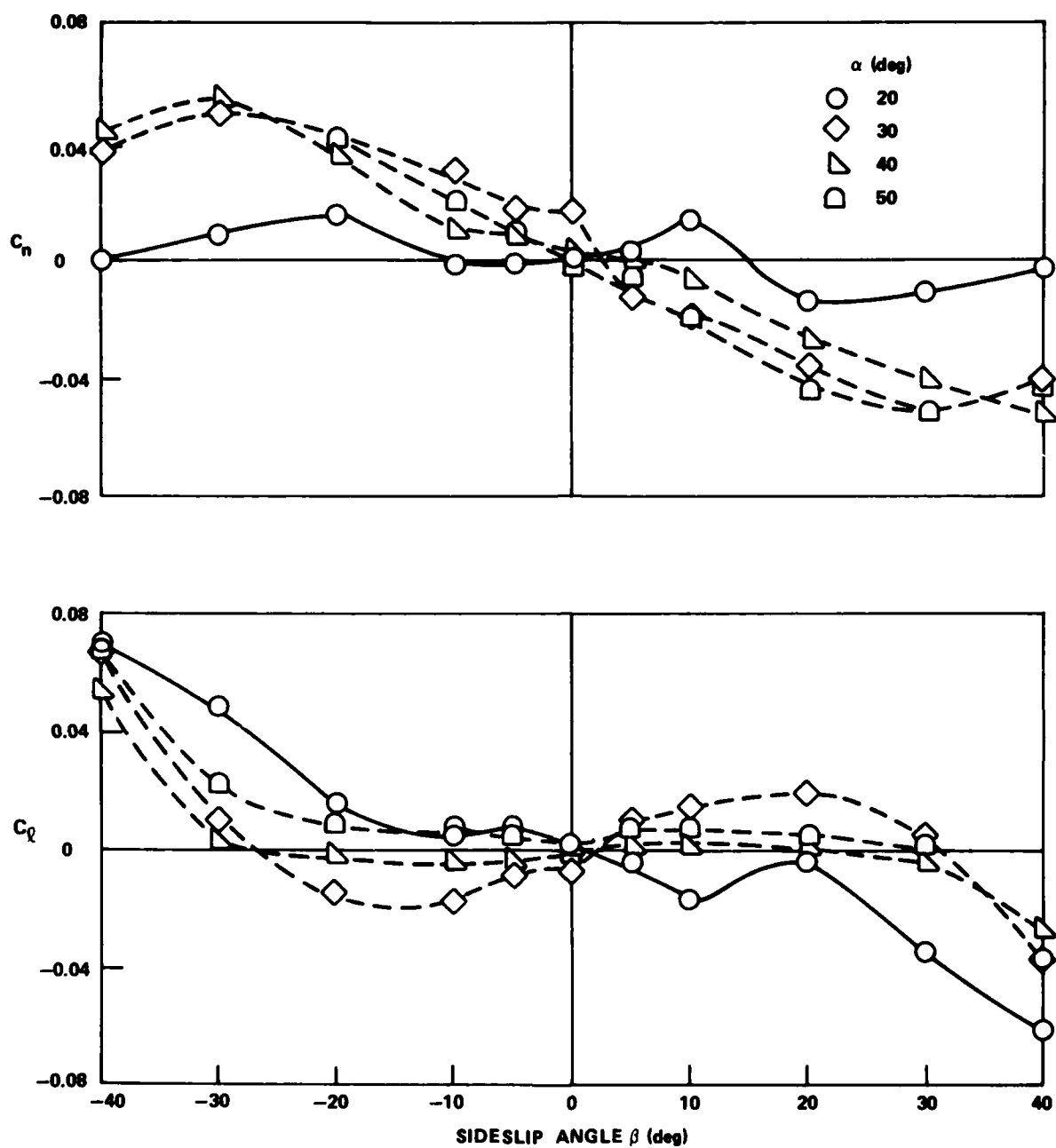


Figure 7 - Post-Stall, Lateral/Directional Characteristics of the X-13 Configuration
(From Reference 13)

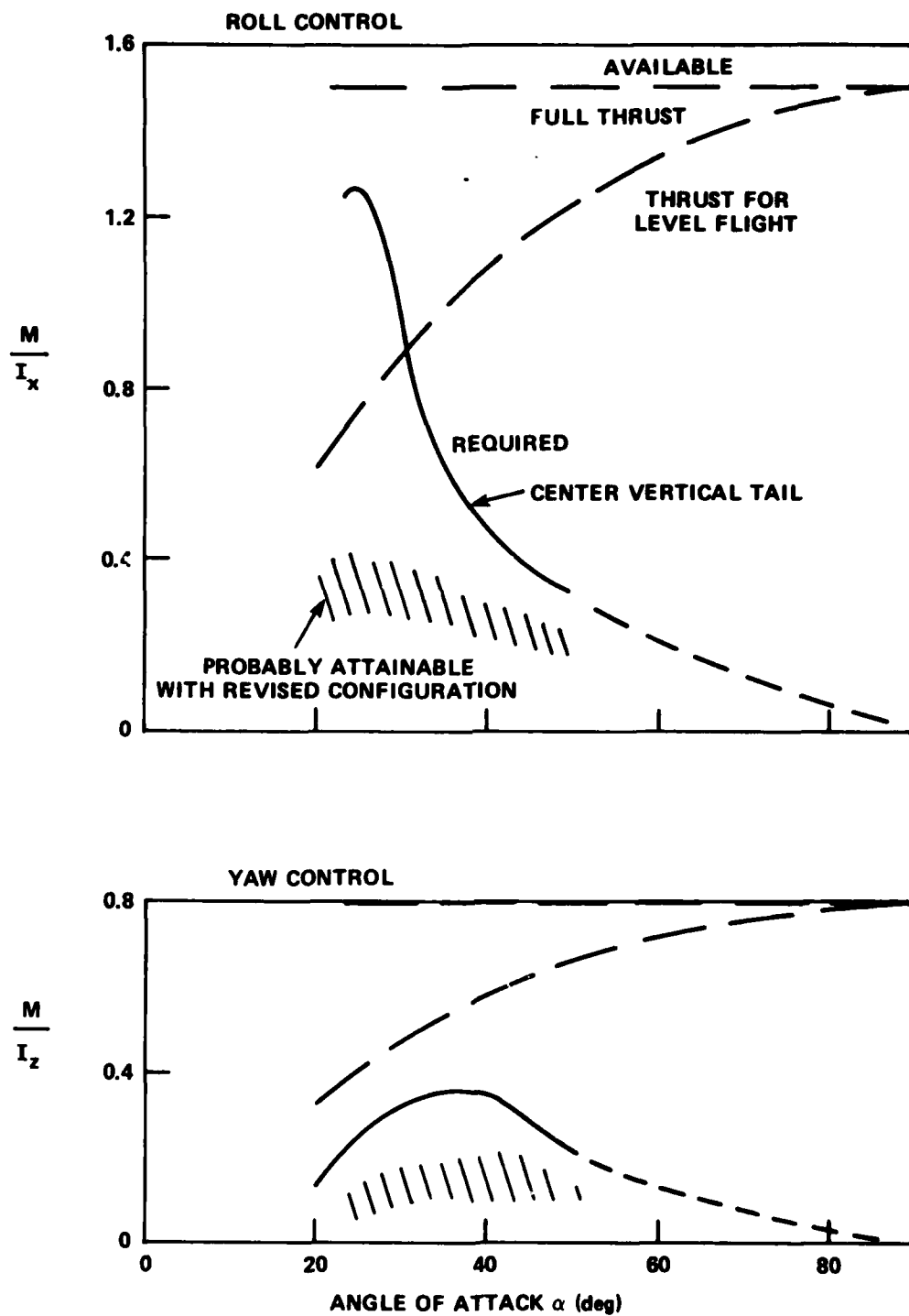


Figure 8 - Lateral/Directional Control in the Post-Stall Region

Reference 14 gives some insight into the effects of some configuration variables on the post-stall, lateral/directional characteristics and by inference some ideas as to what might be done to improve the characteristics. Comparison of the tail-off yawing moment data with the data for the top vertical tail (high wing) shows that in the post-stall range the vertical tail is actually destabilizing (as it is on many airplanes). Apparently, the vertical tail is in an adverse side wash from the flow field generated by the forebody of the configuration. Even so, the model was flyable, particularly with a roll damper. Adding a lower vertical tail reduced the directional stability slightly but extended the negative dihedral effect to high sideslip angles and made the model unflyable, even with artificial damping. Converting the model to a low wing configuration reduced the directional instability to the tail-off level and gave a high level of positive dihedral effect. Unfortunately, the model was again unflyable without artificial stabilization because of an unstable lateral oscillation.

In addition to the experience with the X-13, the data of Smith¹³ and Lovell and Parlett¹⁴ suggest that it is desirable to minimize the extremes of both directional stability and dihedral effect (positive or negative). Unfortunately, there is little available data (the data of Greer¹⁵ are of some help), and there have been no systematic investigations that are of help in designing for good post-stall, lateral/directional characteristics.

Headley⁶ presents a good review of most of the available data and gives guidelines for the forebody configuration to minimize the yawing moments at zero sideslip caused by the unstable interaction of the nose

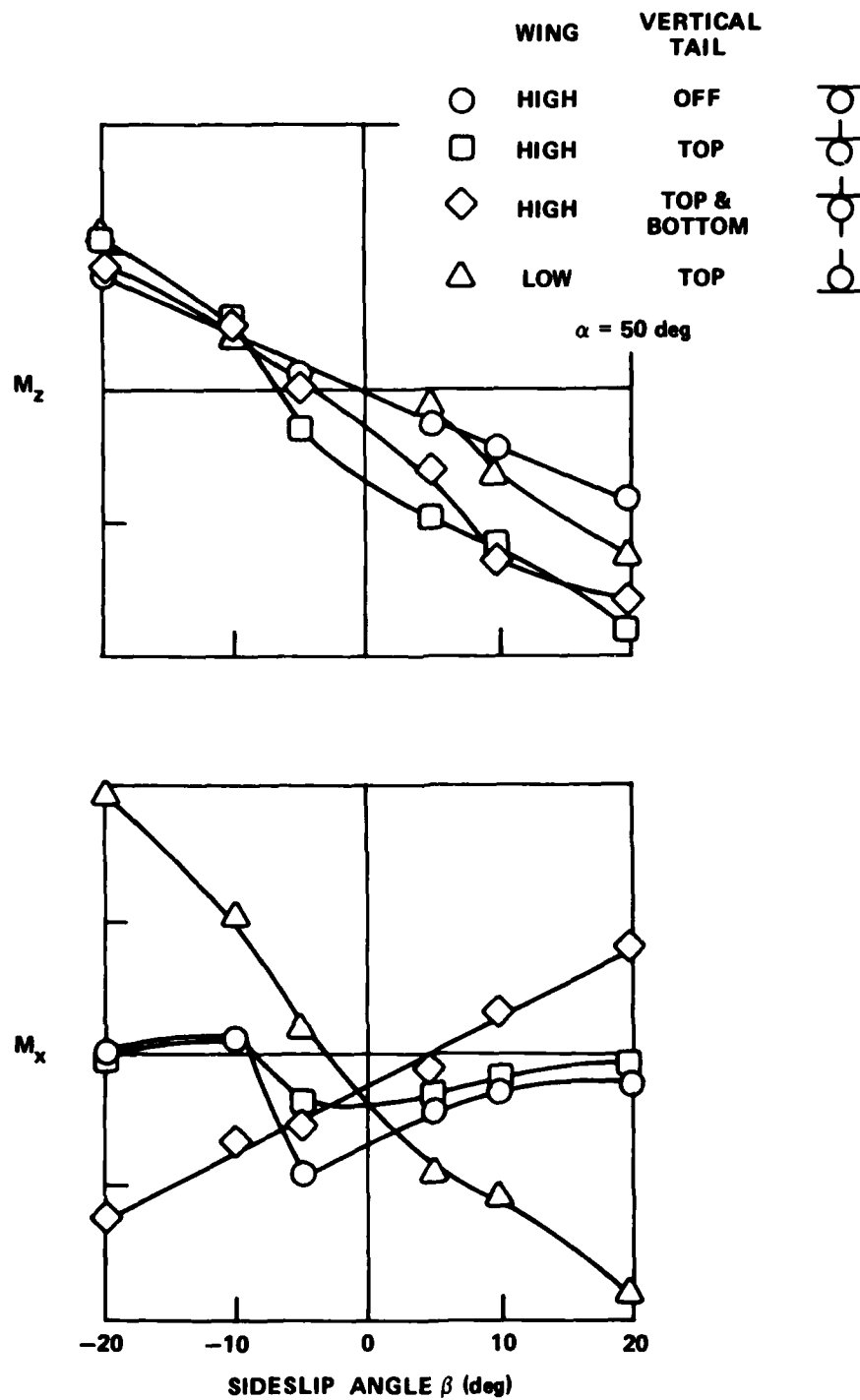


Figure 9 - Effect of Vertical Tail Configuration on Post-Stall, Lateral/Directional Characteristics

(From Reference 14)

generated vortices. A "shark nose" configuration to minimize this problem is indicated on the configurations in Figures 3 and 4.

Headley⁶ also discusses the effects of the vortex flow from the leading edge extensions on the contribution of vertical tails. This review and the data of Figures 7, 8, and 9 suggest that proper placement of twin vertical tails with respect to the canard/forebody flow field should significantly improve the post-stall, lateral/directional characteristics relative to those of a center tail configuration. The size and positioning of the twin verticals will have to be determined by wind tunnel tests. It may also be necessary to compromise the size and span of the canards or leading edge extensions in arriving at a good overall configuration.

Ventral surfaces and the possibility of varying the geometric dihedral of the outer wing panels (Figure 3) between the conventional and the post-stall flight regimes as a means of obtaining acceptable characteristics throughout the angle of attack range should also be investigated.

CONTROL SYSTEM AND ENGINE MODIFICATIONS

CONTROL REQUIREMENTS

The control requirements in AGARD Report 577 ("V/STOL Handling and Discussion," Dec 70) were used in sizing the control system. Recommended in AGARD Report 577 are minimum levels of control power for maneuvering and typical total levels. The latter, which were used for this study, are:

$$\text{Pitch} \quad \frac{M_y}{I_y} = 0.8 \text{ rad/sec}^2$$

$$\text{Roll} \quad \frac{M_x}{I_x} = 1.5 \text{ rad/sec}^2$$

$$\text{Yaw} \quad \frac{M_z}{I_z} = 0.8 \text{ rad/sec}^2$$

Moments of inertia were estimated from the data in Figure 10, which presents the effective radius of gyration of fighter-class aircraft ranging in size from the F-5 to the F-14.

HOVER AND TRANSITION CONTROL CONCEPT

In hovering and transition flight, a VTOL aircraft must derive its control from the engine either from bleed air or by thrust vectoring. Bleed air is very expensive in terms of thrust penalty, resulting either in significantly oversizing the engine to provide the bleed air or over-temperaturing the engine during the brief intervals when bleed air is being used. Eilertson¹⁶ flew a small-scale, VATOL, remotely piloted vehicle in hovering using only thrust vectoring for control about all three axes. A direct scaleup of the concept to fighter size aircraft showed that vanes in the exhaust of a conventional round nozzle could not provide enough moment for roll control because the moment of inertia I_x increased by the square of the dimensions and the control moment M_x increased only by the first power. A modification of the concept evolved, as shown in Figures 3 and 4.

This control system envisions ducting the fan air to two two-dimensional nozzles, one on either side of the core nozzle. These two-

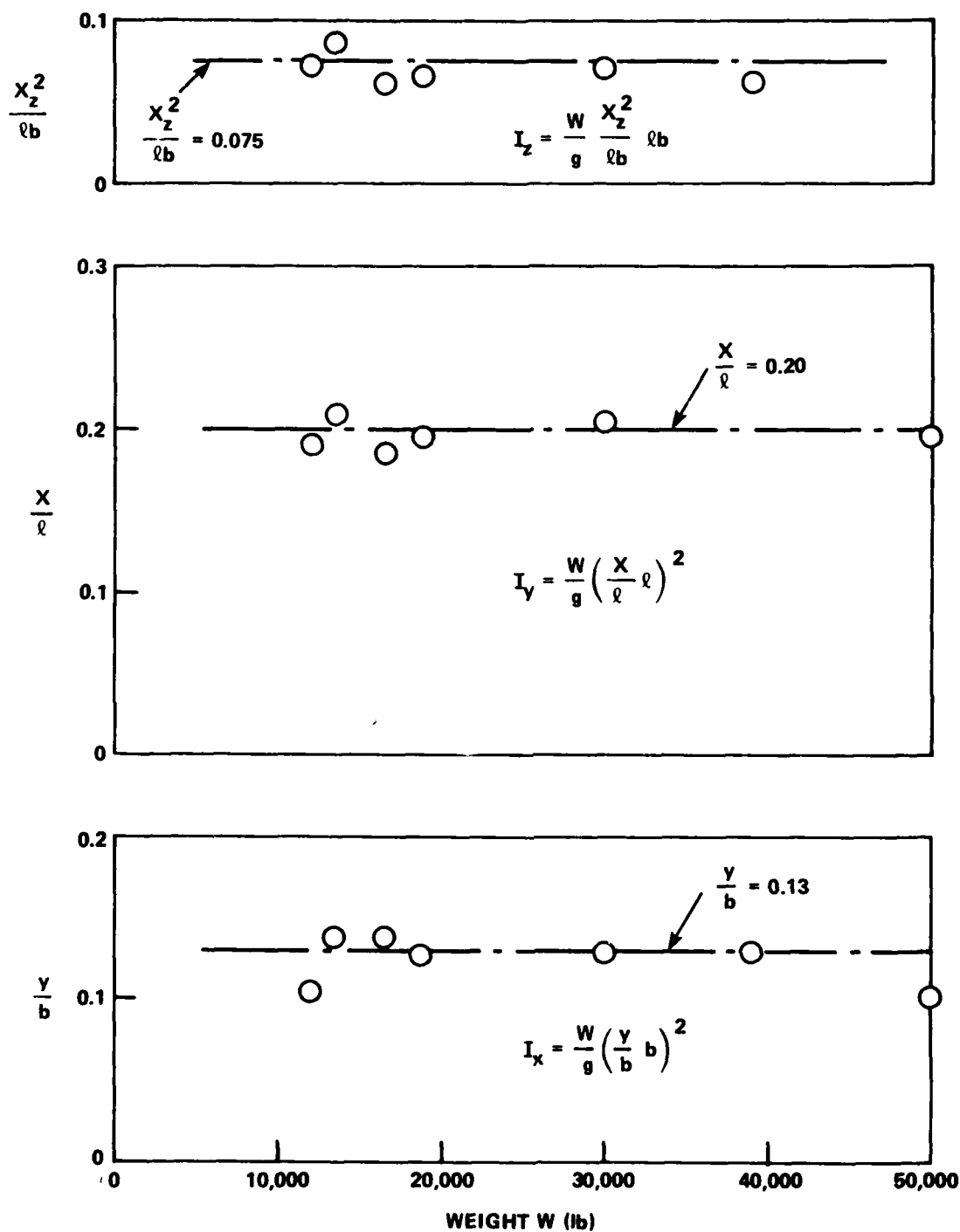


Figure 10 - Effective Radii of Gyration of Fighter Class Aircraft with Stores Off

dimensional nozzles are deflected differentially for roll control and together for pitch control. On a new engine, as for the supersonic fighter of Figure 3, the fan flow would be taken off downstream of the fan section, through two duct burners, to the two-dimensional nozzles. These nozzles would have to be convergent-divergent nozzles as well as provide thrust deflection. Studies of two-dimensional, convergent-divergent nozzles have indicated that a ± 30 -deg deflection is attainable. With an engine bypass ratio of about 1.0, each two-dimensional nozzle would provide about one-fourth of the thrust-only about a ± 20 -deg deflection is needed for control. The remainder of the deflection would be available for high lift (along with the all-moving/articulated-flap canard) in short takeoff (STO) operation. Yaw control would be provided by lateral deflection of the core nozzle.

CONTROL IN OTHER MODES OF FLIGHT

A recent DTNSRDC/NASA-Langley piloted simulation study of combat maneuverability in the post-stall region indicates that reaction control is a tremendous advantage. Also, the levels of control required for VTOL are more than adequate (even after allowing for the control thrust changes with altitude and Mach number) for fighting in the post-stall region. Thus, on a VATOL, two separate control systems (as required on most other VTOL types) should not be needed. This, of course, means that the engine and nozzle controls now become primary safety-of-flight items and must be subjected to all the reliability and redundancy considerations normally required on conventional controls. The resulting

system should save weight and improve overall aircraft reliability and maintainability relative to aircraft requiring separate hovering and transition and conventional control systems.

RESEARH AIRCRAFT

To study the VATOL operations of the concept, research aircraft would not need an afterburning engine. Thus, considerable development cost and time could be saved by using an available engine. Figures 4a and 4b illustrate two engine possibilities for research aircraft.

With the Pratt and Whitney YF 401 engine operated dry, the fan air could be taken off at the beginning of the afterburner section and ducted to the two-dimensional nozzles. Only simple convergent nozzles would be required. However, because the bypass ratio is about 0.6, the fan thrust is only 30 percent of the total, and a ± 31 -deg deflection is required for roll control.

The research aircraft powered by the General Electric TF 34 engine (Figure 4b) would have to use a slightly different variation of the control scheme. Because of the high bypass ratio, the fan thrust is 80 percent of the total. Only a ± 10 -deg deflection is required for pitch and roll control; however, yaw control would also have to be supplied by the fan thrust, and vanes would have to be used to deflect the thrust the ± 10 -deg required.

The research aircraft powered by the Pratt and Whitney YF 401 engine (Figure 4a) would be closest to an actual fighter, particularly if the alternate engine and nozzle arrangement were used. The TF 34

powered research aircraft is much smaller and lighter than the YF 401 powered aircraft and, therefore, probably the least expensive.

ALTERNATE ENGINE AND NOZZLE CONCEPT

The control concepts are built around vectoring nozzle concepts that have been studied and should be relatively easy to develop. With an afterburning engine, however, three separate burners must be developed, controlled, and maintained. An alternate approach is shown in Figure 11. The output from a fairly conventional combined flow afterburner is ducted to two widely separated, two-dimensional nozzles. The nozzles are deflected together for pitch control and differentially for roll control, as before; but because all of the thrust is available for control, the deflections required are reduced one-half, about ± 8 -deg for pitch and ± 10 -deg for roll control.

Yaw control is obtained by differential nozzle area change to transfer thrust from side to side. Even with the capability to almost close one nozzle and double the area of the other, a wide spacing is required. This may create flow distribution and cooling problems in the afterburner and require a longer than usual afterburner section. Also, less than 100-percent thrust transfer must be used so that the pitch control can counter the tendency of combined full yaw and full roll control to produce an unwanted pitching moment input. Nevertheless, the concept should be investigated because it is much cleaner aerodynamically and is probably lighter, easier to maintain, and should be more reliable than the three-burner concept shown in Figure 3.

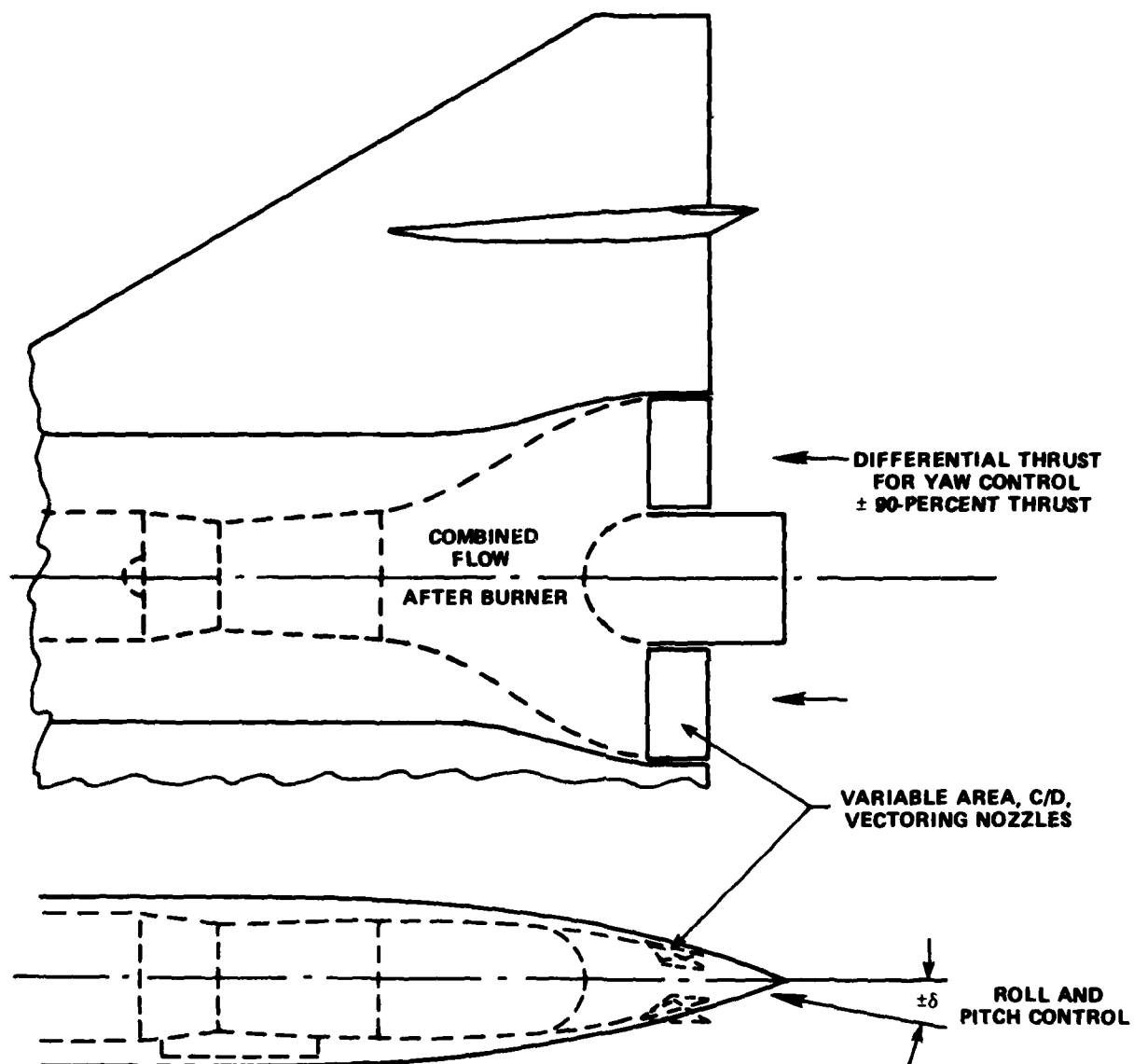


Figure 11 - Alternate Nozzle and Engine Arrangement

CREW STATIONS

One of the primary problems facing the VATOL concept is the combined physiological and psychological problem of "the pilot lying on his back." The primary reason a research aircraft is needed is to dispose of this problem by developing techniques and demonstrating that the VATOL concept can be operated in all expected conditions.

One of the primary uses of a research aircraft will be to develop techniques for operating in all weather conditions. Much work on VTOL instrument flight rules (IFR) operations is currently underway and more will be done in simulation programs specifically directed at VATOL operations. But, eventually, the final development and demonstration must be done in the air. For this reason, the research aircraft suggested in Figures 4a and 4b are shown with two seats - one for the research pilot and one for a safety pilot during the techniques development phase.

The main concern of how to tilt the pilot to a moderately upright attitude as the aircraft tilts to the vertical must be worked out in piloted simulations before a research aircraft is built. Figures 3 and 4 show seats that tilt through to about 45 deg, as used on the X-13 and XFY-1. In an operational VATOL, however, it may sometimes be necessary to start the transition from instrument to visual flight during the transition from horizontal wing-borne flight to jet supported vertical attitude. If only the seat is tilted, the distance from the pilot's eyes to the instrument panel will be changing and may create problems for the pilot in changing from inside to outside reference. It may be necessary to tilt the entire pilot station, as suggested by Gerhardt and Chen¹⁷ (Figure 12), or to tilt the entire cockpit, as suggested by Newsome and Anglin.¹²

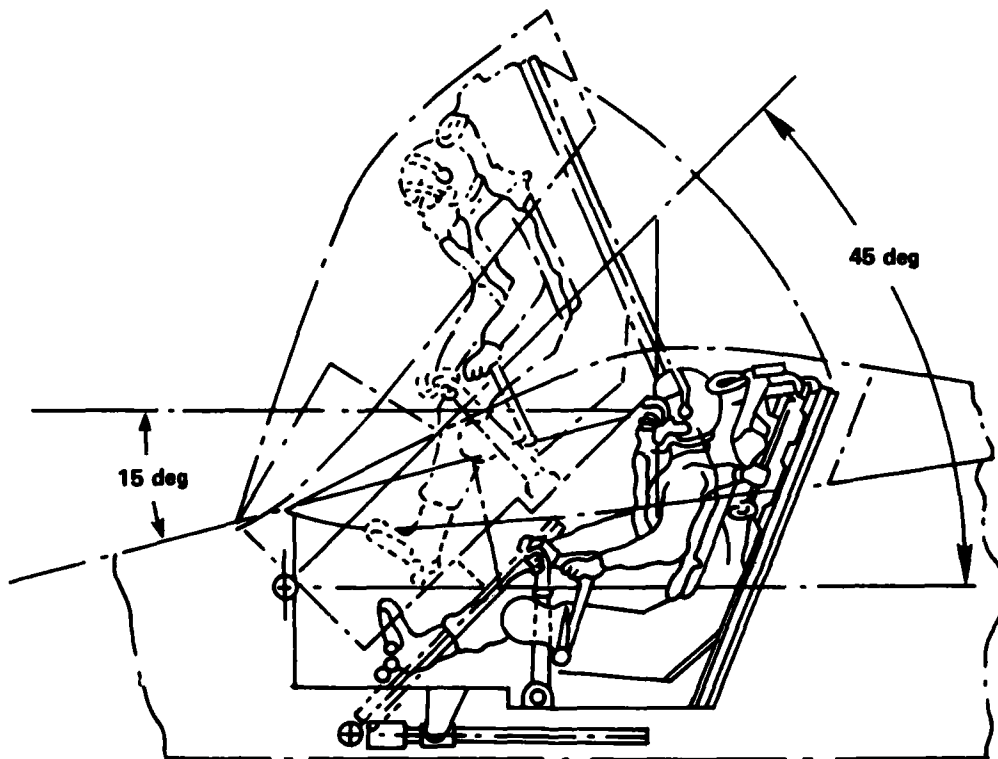


Figure 12 - Articulating Crew Station
(From Reference 17)

STO, TAXI, AND GROUND HANDLING GEAR

The VATOL concept assumes either a vertical or a short takeoff but always assumes a vertical landing. A landing gear capable of absorbing high sink rates and having a high braking energy capacity is therefore unnecessary. (The X-13 was designed to use only a nose hook and two braces to hold the wings parallel to the landing platform. The landing gear shown in Figure 2 was a temporary feature of the test program.) However, some means of ground handling must be provided such as a separate dolly, which creates extra logistics problems. A possible compromise is suggested in Figures 3 and 4.

RESEARCH AND DEVELOPMENT NEEDS

A complete review of the work required and the problems to be overcome in developing a VATOL are presented in Reference 11. Only those areas where recent technology presents new opportunities or where past experience or future requirements suggest the need for special attention are reviewed in this report. Figure 13 presents an approximate time-phased, but not time-scaled, array of the key research and development needs.

The primary need now is for a VATOL research aircraft to fully explore, develop, and demonstrate (a) the operational techniques that a VATOL will have to use in service and (b) the ground and/or ship based equipment that will be required to support aircraft operations. Prior to the design and construction of such a research aircraft, however, a number of preliminary studies beyond the usual trade-off and design studies must be undertaken.

VATOL KEY R&D NEEDS

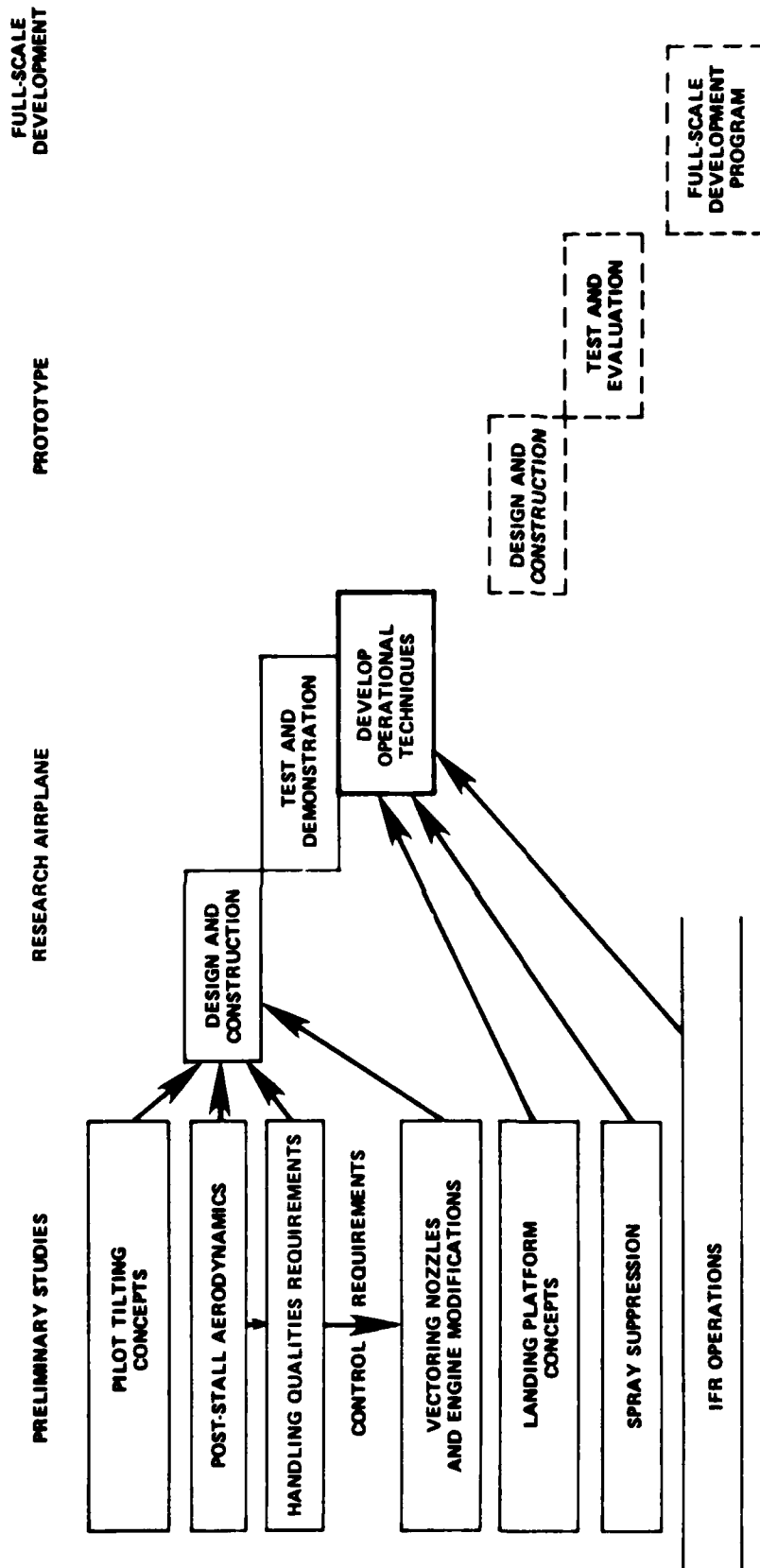


Figure 13 - VATOL Unique Research and Development Needs

PILOT TILTING

Although tilting the seat 45 deg was adequate for the X-13 and the XFY-1 test beds, this approach may not be adequate for an operational aircraft. The relative distance from the pilot's eyes to the instrument panel changes as the seat tilts, as does the pilot's inside to outside visibility. These changes require varying the refocusing of the eyes and may present problems in converting from instrument to visual flight. A few competitive pilot simulations using various seat tilting, crew station tilting, and, perhaps, even tilting of the entire forward fuselage, must be undertaken to develop a sound basis for decision on the best approach for an operational aircraft.

POST-STALL AERODYNAMICS

An area of emerging importance for highly maneuvering aircraft as well as for VATOL aircraft is post-stall aerodynamics. And, while little systematic research has been done, much has been learned in exploring and improving the characteristics of aircraft developed in recent years. Maximum lift can be increased and stall delayed by the use of leading edge extensions and canards to control vortex lift. Lateral/directional characteristics can be improved by proper shaping of the fuselage forebody and by proper sizing and positioning of vertical tails with respect to the flow field. The general flow phenomena are beginning to be understood, but good characteristics can only be obtained as the end result of an extensive wind tunnel program, guided and evaluated by concurrent aircraft design studies.

HANDLING QUALITIES

The handling qualities requirements for VTOL aircraft have been derived largely from experience with horizontal attitude types. The moments of inertia and the pilot are oriented differently in a VATOL, and there may be significant differences in the control power requirements- particularly for roll and yaw. Also, ship motions, which may make a significant difference in the requirements, have not been included in the current requirements. Piloted simulations in hovering and transition using the aerodynamic characteristics from the post-stall aerodynamic studies, ship motions, and engine gyroscopic effects are needed to establish handling qualities requirements specifically for VATOL aircraft.

VECTERING NOZZLES AND ENGINE MODIFICATIONS

A series of engine and nozzle configuration studies to evaluate the potential of various nozzle arrangements for meeting the control requirements are necessary. These studies must be followed by hardware tests of the more promising concepts to insure realism of weight and performance estimates.

Additional modifications, at least to the lubrication system, will be necessary to accommodate the requirement for the engine to run on end for upwards of a minute.

LANDING PLATFORMS

The landing platforms for a VATOL aircraft correspond to the runway for a CTOL aircraft. A runway is capable of accommodating a wide variety

of aircraft and the VATOL landing platform should also be capable of handling a variety of aircraft designed for a variety of missions.

As part of the process of deciding on the configuration and size of the landing platform, design studies to evaluate the potential of the VATOL concept for applications to other missions (ASW, AEW, Attack, etc.) should be made to determine the landing platform concept, size, and weight handling capability.

SPRAY SUPPRESSION

The use of VATOL aircraft from ships usually envisions the landing platforms located over the stern or the side of the ship with the jet exhaust clear of the ship. The exhaust will, therefore, impinge on the sea and raise spray which may interfere with operations. The X-13 encountered this problem in a demonstration when crossing the lagoon in front of the Pentagon.¹¹ A recent simplified analysis of the problem¹⁸ indicates that the operating height to stay above the spray is a function of the square root of the aircraft weight, and that the minimum height for the 25,600-pound fighter of Figure 3 would be 80 to 100 feet to stay completely out of the spray. The aircraft may not have to stay completely above the spray, however, because the top of the spray cloud is very diffuse and some spray may be tolerable.

To verify the analysis of Reference 18, a large-scale experimental program is needed to determine the density distribution of the spray, the extent to which vision may be obscured, and the severity of other operating problems, such as corrosion. Also, methods of relieving the spray problem should be investigated, such as deflectors on the side of the ship or high

pressure water jets blowing laterally from the side of the ship below the landing platform to deflect and suppress the spray.

IFR (INSTRUMENT FLIGHT RULES) OPERATIONS

There have been continuing efforts within both the Navy and NASA on the special problems and potential of operating VTOL aircraft in low visibility conditions. This work needs to be extended to the VATOL concept with its pilot tilting provisions. Both the effect of low visibility operation on the requirements and design of the pilot tilting provisions and the effect of the reorientation of the pilot on the displays and aircraft control system need to be determined, and appropriate equipment and design requirements should be developed.

CONCLUSIONS

Of the various approaches to VTOL capability, previous studies have shown that the VATOL concept requires the least change from a good CTOL configuration and has the least weight penalty. The present study suggests a control concept that could be used in all flight modes, thus, further reducing the VTOL penalty.

The VATOL concept, however, involves an unusual operating mode which consists of flying the aircraft through the stall in the transition from wing-born horizontal flight to jet-born vertical attitude. Two previous VATOL test beds, the X-13 and the XFY-1, have demonstrated that this type of operation can be done in numerous research flights. A VATOL research aircraft is needed now to explore, develop, and demonstrate the full operational feasibility of the VATOL concept for routine service use.

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